Summary of Experiments with Te Thickness Variation
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5 Sept 03

Dave and Ken: this is a brief summary of experiments we have performed to examine the effect of Te thickness on cell stability. At the end we comment on how these results are related to humidity effects during processing and stress.

1) From IEC Monthly report to NREL for Feb 2003

IEC vapor transport CdTe devices with Cu doped C ink conductor. Four samples processed with 20, 30, 45, 60s NP etches and one sample processed with a 20s Br_2 etch. Estimated Te thicknesses for these etches are ~1 nm for Br_2 etch, < 75 nm for 20-45 sec NP etch, and ~100 nm for 60 sec etch. CdTe was contacted with graphite paste containing 6% w/w Cu powder and annealed. Stressed for 50 days at 85C in dark and room air. Little degradation was measured in Voc and Jsc. However, significant changes were observed in Roc, increasing with shorter etch times (thinner Te) – see fig 1. The 60s etched piece showed almost no Roc decrease.

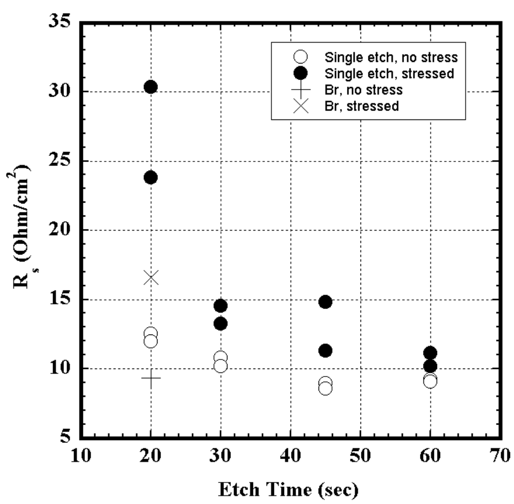

Figure 1. Plot of R_s, before and after stressing at 85°C in air and in the dark, vs. etch time for devices that received NP etching during back contact processing. The R_s values, before and after stress, for the device etched in 0.05% Br_2/methanol are also shown.

2) From IEC Annual Report to NREL for 8/00 to 8/01, pp. 36 to 39

Interactions between the secondary contact (C, Mo, Ni) and the interlayer (Te/Cu) may play a significant role in controlling both initial performance and stability. First Solar CdTe/CdS was processed with Te vapor at different thickness (10 nm and 100 nm) but fixed Cu thickness. Cells were stressed at –1 V, 0V and +1 V in the dark for 10 days at 60C. For devices with Ni and Mo contacts, greater stability was found with the thick Te layer, with the best stability for the Mo contact. For cells with undoped C ink conductor, good stability was found for stress at 0V bias. Comparable stability was found for reverse bias stress, independent of Te or Cu thickness. Best stability for forward bias stress found for cells with thick Te and no Cu. Poor stability for forward bias stress of cells with thin Te and no Cu and thick Te with or without Cu.

3) From IEC presentation to CdTe Team (Jan 27-28 2000) Slide V.

First Solar CdTe/CdS contacted with 100 nm Te/Mo ("thick Te) with no Cu. Initial performance comparable to control cell with Te/Cu/C contact (9-9.5%). Stressed in light at –0.5 V, 0V, Vmp and Voc at 100C for 10 days. The Te/Mo contacted cell was most stable at FWD bias.

With IEC vapor Te/Cu contact with undoped C ink conductor, devices with 110 nm Te degraded significantly more than those with 10 nm Te during the 100C stress!

4) From IEC Annual Report to NREL for 8/98 to 8/99, pp. 87 to 93.

p. 87: First Solar CdTe/CdS and IEC vapor Te/Cu contact with undoped C ink conductor. For fixed quantity of Cu (8 nm), best initial performance (11%) found for single Te deposition (~10 nm) and lowest (9.7%) for 4X Te (~40 nm). The Voc and FF decreased with increasing Te thickness. No correlation found for Roc or Gsc. This can be interpreted as an effect of Cu-Te chemistry on availability of Cu for doping CdTe.

p. 93: Comparison of cells with different Te formation methods. Devices made with no Cu layer and undoped C ink conductor. Found similar initial performance for 10 nm Te by vapor deposition, 1 nm Te by wet etch (Br_2) and 100 nm Te by BDH process. After stress for 6 days at 100C in room air, cell with 100 Te by BDH was the most stable and exhibited the least rollover.

Summary and Comments:

For devices with no Cu, the best stability is found for devices processed with thick Te.

For devices where Cu is delivered by diffusion from a graphite paste, the lowest Roc and best stability is obtained for thicker Te. Diffusion of Cu from a paste through the Te film is a relatively slow process, based on driving force of concentration gradient, which is lower than for a discrete film; the Cu is present as distributed clumps in the paste, reducing the effect concentration for diffusion.

For devices where Cu is delivered by diffusion from a discrete Cu film deposited onto a Te film, the best stability depends on the contact material used (Mo and Ni are better than C ink). This may have more to do with the batch processing methods and atmospheric reactivity with the exposed Te/Cu surface than with any other fundamental property. The C ink is applied to the Te/Cu surface on the lab bench, while the metals are applied in a vacuum, during which the samples become heated and have time to desorb atmospheric contaminants.

The effect of humidity on stability after stress or storage may be related to these observations, implicating the Te/Cu stack as a chemically sensitive structure. C paste will absorb H_2O vapor (as reported by the Matsushita group in the l990's), affecting not only electrical behavior, but also mechanical adhesion. All of above, plus what we presented at the last team meeting, indicates the need to consider at what points during device processing do the samples see atmosphere. We believe that the promising results shown by Sampath, using a Cu-based contact, are the result of an unbroken in-line process for contact formation. Our present focus is on quantifying the Te-Cu-contact processing quandry, and more importantly, developing ways of overcoming it through chemical stabilization of the back surface during processing.